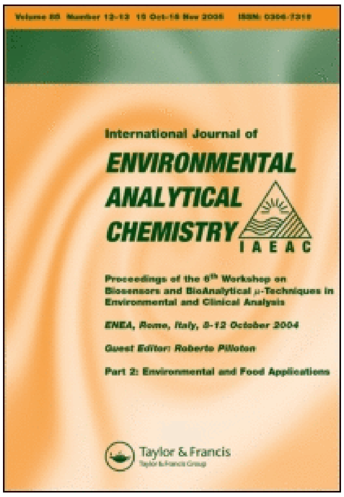

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Passive Biomonitoring with Lichens as a Part of an Integrated Biological Measuring System for Monitoring Air Pollution in Switzerland

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PASSIVE BIOMONITORING WITH LICHENS AS A PART OF AN INTEGRATED BIOLOGICAL MEASURING SYSTEM FOR MONITORING AIR POLLUTION IN SWITZERLAND

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Passive Biomonitoring with the folious lichen Hypogymnia physodes (L.) Nyl. has been tested in Switzerland. Multielement analyses enable qualitative and quantitative conclusions about the composition and amount of important active pollutants. Many elements correlate well with the general air pollution indicator IAP18. Hypogymnia physodes possess good accumulation capacity for important air pollutants. The method has been calibrated for Pb and Cu with technical deposition measurements. The "Passive Biomonitoring" and "Calibrated Lichen Indication Method" compose together an "Integral Biological Testing System for Air Pollution in Switzerland". This system enables detailed statements on total air pollution in general and on single pollutants as well.

KEY WORDS: Air pollution, biomonitoring, biological effects, lichens, multielement analysis, lead, copper, accumulation, ICP-AES.

INTRODUCTION

Tree inhabiting (epiphytic) lichens have been considered to be reliable bioindicators of air pollution for decades.[1,2] Lichens are extremely sensitive symbiotic organisms consisting of fungus and algae, which react to even slightly polluted air. The pollution damages them and, as a result, they can die. The registration of this reaction enables conclusions on the immission situation.

In lichen bioindication, 2 different methods stand out. With the aid of the IAP-method (Index of Atmospheric Purity) an area-wide cadastre of biological effects of air pollution is provided. On the other side passive biomonitoring leads, over extensive multi-element analyses on certain lichen species, to findings on the immission stress by single pollutants. Our studies on these two methods were conducted within the Swiss Federal Research Program No. 14, "Air Management and Air Pollution in Switzerland".

The chief objective of our work with lichens was the development of simple, quantitative bioindication methods, which should enable the registration of total

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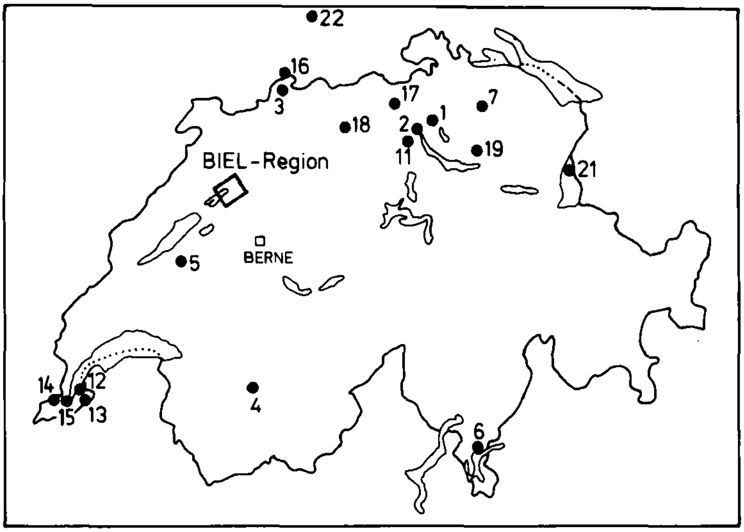

Figure 1 Biel region and Midland stations: 1 Dübendorf-NABEL, 2 Zurich-NABEL, 3 Basel-NABEL, 4 Sion-NABEL, 5 Payerne-NABEL, 7 Tänikon-NABEL, 11 Birmensdorf-EAFV, 12 Anières, 13 Jussy, 14 Meyrin, 15 St. Clotilde-Geneva, 16 Weil a. R. FRG, 17 Lägeren-NFP14$^+$, 18 Auarau, 19 Bachtel-East, 20 Stampfenbachstreet-Zurich, 21 Schaanwald FL, 22 Freiburg i. Br. FRG.

air pollution in the Swiss Midlands (Calibrated Lichen Indication Method),[3–5] and allow detailed statements on specific pollutants (Passive Biomonitoring).

Both methods were developed in the Biel region. They were then tested in the Swiss Midlands, above all on the measuring stations of the NABEL-Network (Federal Air Pollutant Observation Network) and of the EAFV (Federal Institute of Forestry Research) in Birmensdorf (Figure 1).

CALIBRATED LICHEN INDICATION METHOD

The IAP-method, which has been used in numerous lichen studies, was subjected to a wide evaluation. Twenty variations of the IAP calculation were compared to technical immission data using multiple linear regression analysis. In the Biel region the absorption, resp. deposition data of 8 pollutants at 13 sites (SO_2, NO_3^-, Cl^-, dust, Pb, Cu, Zn and Cd) were used. In the Midlands, gas concentration data from SO_2, NO, NO_2 and O_3 at 19 sites were employed.

In both collectives the multiple regression shows a high degree of fitting between the lichen data and the technical immission data. The calculation model with the highest coincidence, IAP18, presents a determination coefficient (R^2) of 0.98 in Biel and of 0.93 in the Midlands. In both cases, the descriptive significance level (P value) of the global hypothesis is smaller than 0.5%. The total immission model IAP18 is based on the frequency of 40 selected lichen species. Based on the regression analysis, none of the tested pollutants can be regarded as genuinely redundant. This is a verification that lichens do not specifically react to single toxic components in the air, but rather indicate the integrative toxic effect of a combination of different biologically relevant pollutants.

The lichen indication method is calibrated with technical immission data and provides, next to a cadastre of biological effects, a total immission cadastre for air quality. This is based on the integral purity index, IAP18. The cadastre of biological effects classifies the following 5 zones with decreasing injury of the lichen vegetation: lichen desert, inner struggle zone, outer struggle zone, transition zone and normal zone. These zones correspond to the five zones of the total immission cadastre: Critical Air Pollution, High Air Pollution, Medium Air Pollution, Low Air Pollution and Very Low Air Pollution.

The calibrated lichen indication method can assist in the early recognition of air hygienic problem areas (air pollution early warning system). It can show up and spatially differentiate the momentary degree of air pollution covering a certain surface. A repetition of the lichen survey enables success verifications after having taken emission reducing measures. For the realization of the Swiss Clean Air Act (Luftreinhalteverordnung) the spatial and time related stress findings of the biological effects and total immission cadastres are especially valuable.

The possibility of an allround evaluation of the air pollution situation is of interest to modern city planners, who are increasingly endeavored to include ecological criteria in their concepts. This is of great human medical-toxicological value, as the lichen zones correlate significantly with the frequency of pulmonar and upper respiratory tract illnesses.[6]

PASSIVE BIOMONITORING

The Calibrated Lichen Indication Method is useful in measuring total air pollution. Precise conclusions on prevalent single pollutants are only possible though, with the aid of Passive Biomonitoring: Multi-element analysis on a selected lichen species can enable qualitative and quantitative conclusions on type and amount of single active pollutants.

It has long been considered as verified that the element content of the plants reflect the environment and especially immission influences. In numerous studies, mosses and lichens have proven to be very reliable accumulation monitors for heavy metal compounds and other toxins.[9,10] The very common folious lichen species which we chose for our study, Hypogymnia physodes, is considered to be one of the most studied plant species in relation to different immission components (SO_2, NO_x, O_3, dust, heavy metals, pesticides and other organic compounds).[11]

A study conducted in the vicinity of a Danish steelwork with transplantations of Hypogymnia physodes (active monitoring) has shown up excellent correlation references to the simultaneously technically measured depositions of 7 important heavy metals (Cd, Cu, Fe, Mn, Ni, Pb, Zn).[12] A country-wide Finnish study with 2 epiphytic and 2 terricolous lichen species shows up highly significant and good correlations between the total sulfur content of the lichen and the atmospheric SO_4 depositions for Hypogymnia physodes and Pseudevernia furfuracea.[13]

The objective of the study at hand was to examine the questions, if such good correlation references exist in field samples not artificially exposed (passive monitoring), and if this certain biomonitor-species is suitable for quantitative analysis of the spatial trace elements immission patterns in Switzerland.

METHODS OF PASSIVE MONITORING

Plant material and random sample concept

The lichen samples of the species Hypogymnia physodes (L.) Nyl. were taken from up to 10 carrier trees in the vicinity of each of the 14 Bieler immission-stations and the site Biel-Magglingen (Edge of the World). These same 10 trees were used in air quality measurements using the Calibrated Lichen Indication Method. As far as possible, 1.0 g of lichen material per tree was collected. One mixed sample consisted of several single plants.

To clarify the background contents of the single elements, the relatively unstressed forest site Forst-Neuenegg, west of Berne, was included in the study. The Bieler sample material was collected in January 1985 and consists of 138 single samples. This results in a very dense biological measurement net. The same procedure was repeated in 1986 on the NABEL network stations and on the EAFV station. All together 40 samples (5–8 samples per station) were taken from the Midland stations.

Multielemental analysis

The multielement analyses were conducted on the ICP-AES (Inductively Coupled Plasma Atomic-Emission Spectrometer) ARL 3580 at the EAFV. The 21 following nutrients and trace elements could be determined in only one analysis process: Aluminum (Al), boron (B), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), potassium (K), lithium (Li), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), anorganic sulfur (Sanor), tin (Sn), and zinc (Zn). In addition, the elements total sulfur (Stotal) and chloride (Cl) could be determined by ion chromatography after Schöniger ashing. The chemical analytics were conducted strictly after the Sanasilva-method, as it was for the needle analysis.[8,14] Because not all samples consisted of the necessary 1.0 g of material, the ICP analysis was conducted by weight.

It was thus possible to determine typical macro-nutrients (P, K, S, Ca, Mg) and micro-nutrients (Fe, Mn, Zn, Cu, Cl, B, Mo), as well as phytotoxic or human-toxic elements (Al, Pb, Cd, Cr, Ni) simultaneously. A fact that should be specially mentioned is, that in plant nutrition, a lot of elements, too highly concentrated, can have toxic effects.[15]

RESULTS

Element content and IAP18-Total pollution zones

Relevant elements are probably the most important issue in every multi-element study. In this case it is the question which of the elements show up any gradients, resp. correlations to the air pollution situation (expressed through the total air pollution indicator IAP18).

The comparison of the most important elements (means per station) with the 5 IAP18 zones of the Bieler biological effects and total immission cadastre is presented in Table 1. All values are expressed in ppm (μg/g dry weight). Roughly four groups of elements can be discerned according to their characteristics:

Group 1: Calcium (Ca) is the only element which shows increasing contents with decreasing total pollution, that means ascending IAP18 values. Thus it is positively correlated to the IAP18. The gradient over the 5 pollution zones stands out well.

Group 2: The element group with Pb, Fe, Cu, Cr, total sulfur, Zn and P shows lower element contents and distinct gradients with decreasing total pollution. Thus, the element contents are negatively correlated with the IAP18. The above mentioned list of elements corresponds to the hierarchy of the pollution gradients in descending order. Lead is found in the zone "Very Low Total Air Pollution" on average 6 times less than in the zone "Critical Total Air Pollution".

Group 3: In the zone "Very Low Total Air Pollution" the 3 elements Li, Cd and Co do show distinctly lower element contents as in the "Critical Total Air Pollution" zone. However, the gradients in Biel are not strictly curvilinear in contrast to those in the NABEL network for the elements Cd and Co.

Group 4: The elements Al, B, K, Mg, Mo, Na, Ni, Sn, Cl and anorg. sulfur (Sanor) show no clear gradients to the total pollution situation. In the NABEL-network, the elements Na, Mo and Ni show distinct gradients to the pollution situation.

An irregularity was found in the lead values of the NABEL-collective in the "Medium Total Air Pollution" zone. The determined lead value (zone average) deviates from the otherwise regular gradient. This is due to the fact, that all the samples from one NABEL station (Dübendorf-EMPA) were taken in the immediate vicinity of a road. The carrier trees used in the registration of the IAP18 are located in quite some distance from any road. Therefore, a false picture is created for the very traffic dependent element lead. Without this station, the lead value sinks to a reasonable niveau (value in parenthesis, Table 1).

The column "background" in Table 1 shows contents that could be valid for the species of biomonitor used in isolated forest areas in the Swiss Midlands. Within the "Critical Total Air Pollution" zone (lichen desert) a comparison between the small city of Biel and the 3 city stations of the NABEL-network in Zurich, Basel and Lugano show up similar values for the immission-ecologically relevant elements Pb, Cd, Cu, Fe, Zn and Ca. This points out that the immission stress in Biel, even considering only single pollutants, differs only unessentially from that of the larger Swiss cities.

Table 1 Comparison of the mean element contents with the 5 zones of the "Biological Effects and Total Immission Cadastres", listed separately according to measuring sites Biel and NABEL.

CADASTRE OF TOTAL AIR POLLUTION		CRITICAL AIR POLLUTION	HIGH POLLUTION	MEDIUM POLLUTION	LOW POLLUTION	VERY LOW AIR POLLUTION	
CADASTRE OF BIOLOGICAL EFFECTS		LICHEN-DESERT	INNER STRUGGLE-ZONE	OUTER STRUGGLE-Z	TRANSITION-ZONE	NORMAL-ZONE	
IAP18		0 10	20 30	40	50	60 70	
Element	Region						Back-ground
IAP18	Biel	11.47	24.05	40.51	53.10	69.80	
	NABEL	2.47		39.22	53.76		
Al	Biel	467	491	508	435	387	363
	NABEL	696		393	490		
Ca	Biel	8470	14198	21279	30900	29395	25501
	NABEL	9928		19427	27362		
Cd	Biel	1.10	1.07	0.76	0.96	0.59	0.22
	NABEL	1.50		1.20	0.85		
Co	Biel	1.03	1.32	0.76	0.94	0.57	0.43
	NABEL	1.20		0.72	0.68		
Cr	Biel	7.20	12.56	4.90	4.67	2.68	1.75
	NABEL	8.22		4.86	2.86		
Cu	Biel	31.05	23.02	16.96	13.05	9.67	4.29
	NABEL	34.31		15.88	9.35		
Fe	Biel	1916	1804	1157	975	590	480
	NABEL	2208		1231	734		
K	Biel	4538	4474	4455	4232	3216	3095
	NABEL	4908		4773	3853		
Li	Biel	0.90	0.90	0.75	0.72	0.44	0.26
	NABEL	1.23		0.71	0.75		
Mg	Biel	570	589	539	527	454	510
	NABEL	775		711	722		
P	Biel	2573	2590	2238	2162	1043	1258
	NABEL	3296		2285	1487		
Pb	Biel	180	94	60	51	31	28
	NABEL	178		175 (54)	46		
Zn	Biel	168	152	114	97	85	44
	NABEL	179		127	96		
Stotal	Biel	3404	3029	2161	2045	1547	830
Cl	Biel	1159	1123	986	1032	1143	1023
Number of Stations	Biel	3	2	4	4	2	1
	NABEL	3		3	2		
Number of Samples	Biel	17	13	37	32	19	3
	NABEL	17		11	11		

Table 2 Significant correlations between IAP18 and the element contents of Hypogymnia physodes, collective Biel (station means).

	Ca	Cu	Fe	Li	P	Pb	Zn	Cl	Stotal
IAP18	+0.87 ***	-0.78 **	-0.91 ***	-0.64 *	-0.54 *	-0.85 ***	-0.73 **	-0.59 *	-0.90 ***

(* = $0.05 > P > 0.01$, ** = $0.01 > P > 0.001$, *** = $P < 0.001$)

Element contents and IAP18-station mean values

The characteristics of the element groups 1 and 2 point out that correlation references between the element contents and the corresponding IAP18 values exist. The univariate correlation of the IAP18 station mean values with the 21 element means provides significant references for the following elements in the Bieler network (Table 2).

The correlation of the elements Fe, total sulfur (Stotal), Ca and Pb are good and highly significant. Out of the combination of both data collectives (Biel, NABEL) additional significant references for the following elements to the IAP18 station means result: Al: −0.53**, Cd: −0.65**, Co: −0.64**, Cr: −0.53*, K: −0.52*, Mg: −0.44*.

The 3-D table in Figure 2 presents a column diagram of the relationship between IAP18 and the elements calcium, total sulfur, iron, lead, copper, zinc and cadmium. The columns in this relative description were normed to the maximal value of every variable.

The distribution diagram (Figure 3) for iron, the best correlated element, visualizes the correlations between the measurements of the Calibrated Lichen Indication Method and those of the newly developed biomonitoring method. The element contents were also compared with the technically measured data from the Bieler stations. Iron shows also a good multivariate correlation to these technical immission measurements. However, comparisons clearly point out that the air quality indicator IAP18 produces a higher correlation with the Bieler air measurements, characterizing the total pollution much more precisely than the iron contents. These results correspond with literature, in which iron is regarded as a possible dominant component for anthropologically caused air pollution.[16,17]

For the elements total sulfur, Ca, Cu, Pb, Zn, Li, P and Cl multivariate comparisons with the Bieler air pollution collective show similar results as iron. Here too, the IAP18 method of characterizing the Bieler pollution collective proves to be the more precise and robust. Multivariate comparisons in the NABEL-network were not possible because there are not enough stations.

Accumulation capacity of Hypogymnia physodes

Interesting results are also shown for the discussion of the accumulation capacity

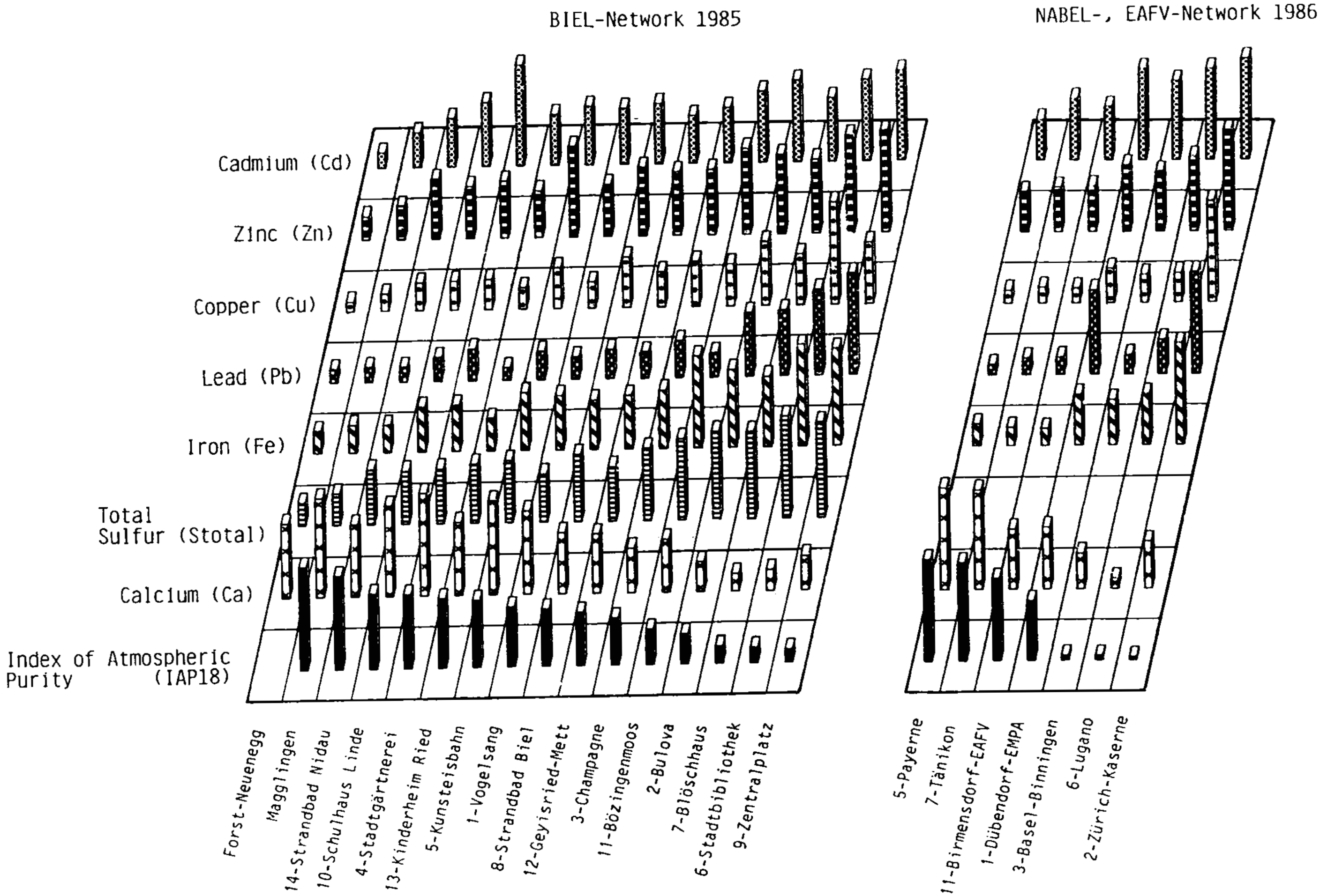

Figure 2 3-D table: Correlation between IAP18 and important elements on the measuring stations in Biel and NABEL. For a better overview, every variable has been normed to the maximal value.

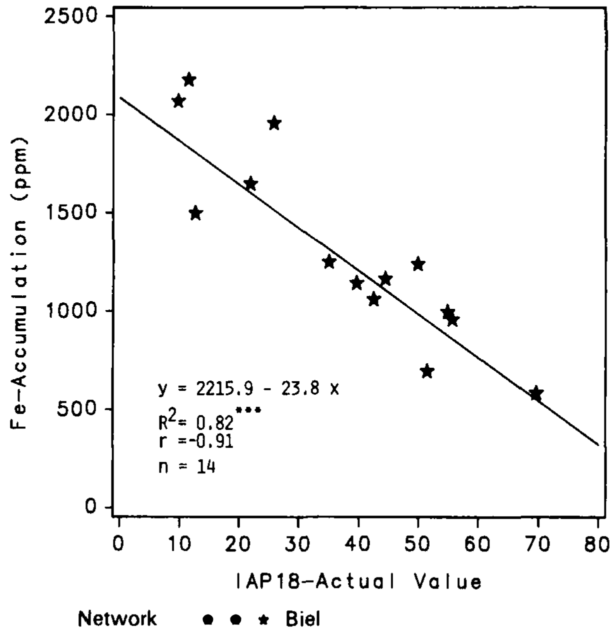

Figure 3 Correlation between iron content of Hypogymnia physodes and total air pollution indicator IAP18, collective Biel (station means).

of Hypogymnia physodes. The issue here is the determination of the accumulation–deposition relationship of the elements for which not only passive (freeland) element measurement data exist, but also technical (experimental) measurement data.

In the Bieler network, the accumulation capacity for Pb, Cu, Zn and Cd was to be clarified in comparison with the Bergerhoff deposition values, and anorganic sulfur (Sanor), resp. total sulfur (Stotal) in comparison with SO_2 (Liesegang method, annual and 5 year mean). In the NABEL network these comparisons were only possible for the element Pb.

Lead is an important immission component in the Bieler surroundings. As a consequence of its high correlation to the motorized traffic frequency,[18] it can be considered to a certain extent as a substitute for the missing NO_x measurements.

Figure 4 shows the calibration with the regression model for the element lead. The relationship is linear and shows a high statistic quality with an $R^2=0.84$, which is equivalent to a correlation coefficient of $R=0.91$, this with a high significance of $P<0.0001$. The calibration for Pb could be validated in the NABEL network. The corresponding stations are especially indicated in the correlation plot.

The comparison of the lead-border values after the "Clean Air Act" (LRV) ($Pb<100\,\mu g/m^2\,d$, annual mean) with the accumulation values shows that for lead values >150 ppm (mean) in the lichen Hypogymnia physodes, pollution infringements are probable. The NABEL stations, Zurich and Dubendorf, had to be

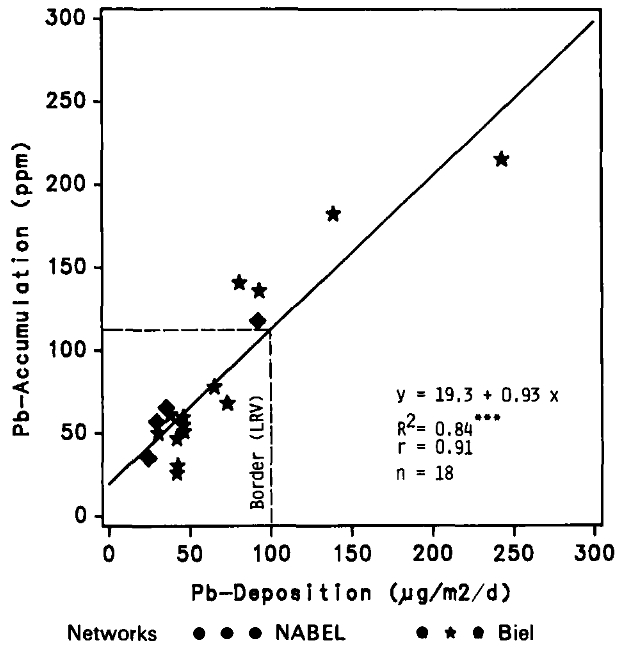

Figure 4 Accumulation capacity of lead (Pb): Regression model between lead deposition (Bergerhoff, annual mean) and lead contents of Hypogymnia physodes (station means), measuring stations in Biel ★, NABEL stations ◆.

excluded from the model calculation. In both cases, the sample sites of the biomonitoring measurements and the technical measurements differed so strongly, that the biological sampling for the element lead cannot be considered representative. The importance of the precise standardization of the sample sites is made exemplary by the element lead. Sites directly influenced by traffic usually deviate by a factor of 2–4 from more protected courtyard situations (Zurich, Dubendorf), as illustrated in Figure 1.

The calibration of copper ($R^2=0.82$***, Figure 5) shows good results as well. Zinc has much greater deviations, due to direct contamination by galvanized chain-link fences and street lamps. Zinc measurements in lichen have proven to be unproblematic in the method oriented supplementary study. There, zinc shows very minimal site deviations and a high selectivity between the stations. Finally, cadmium does not correlate with the corresponding technical deposition data. The Bieler network Cd-data are the subject of several methodical investigations, which indicate that contamination in single measuring sites can falsify results.

Anorganic sulfur (Sanorg), which does not correlate with the IAP18, shows a weak correlation of $R=0.62$* to the SO_2 annual, resp. 5 year mean values (Liesegang method) of the Bieler network. On 7 stations of the NABEL network no verified correlation exists between anorganic sulfur and the SO_2 concentration data. The total sulfur (Stot) on the other hand, correlates well with $R=0.90$*** to the IAP18. Only the SO_2 5 year mean (Liesegang method) shows a significant correlation to the total sulfur data, this on 14 stations in Biel. Unfortunately, there are no corresponding total sulfur measurements from the NABEL network.

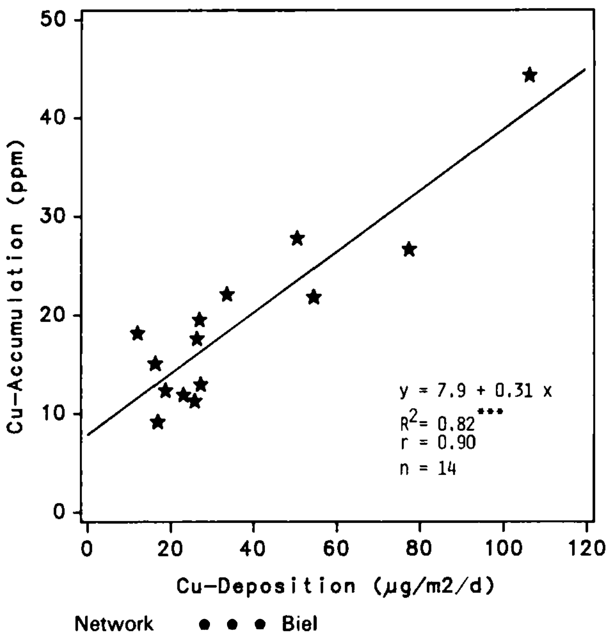

Figure 5 Accumulation capacity of copper (Cu): Regression model between copper deposition (Bergerhoff, annual mean) and copper content of Hypogymnia physodes, collective Biel (station means).

For the significant elements, Pb and Cu, the results for Passive Biomonitoring show a good correspondence to the active biomonitoring of Pilegaard[12] and Takkala.[13] At 10 stations Pilegaard found an $R^2 = 0.90^{***}$ for lead. In the Bieler region there was $R^2 = 0.86^{***}$ on 14 stations, and for Biel and NABEL together $R^2 = 0.84^{***}$ on 18 stations. Pilegaard found for copper $R^2 = 0.86^{***}$, in Biel we found $R^2 = 0.82^{***}$. These results can be considered as very good, considering the fact, that Pilegaard placed his lichen samples directly next to the deposition measuring devices, while we collected our samples in the vicinity of the immission measuring stations ($r \leqq 250$ m), this partly in urban regions with immission conditions differing over small areas.

In the Finnish study by Takkala correlations for SO_4 deposition data were calculated, while in our study SO_2 data were used. This discrepancy makes a comparison of the two studies difficult, because the two pollutants cannot be brought into relation with each other. Nevertheless, both results verify the fact, that significant correlations exist between the sulfur contents of the lichen Hypogymnia physodes, and the absorption and deposition pollution of sulfur dioxide and sulfate.

Principal component analysis of all elements

A principal component analysis was conducted on each of 3 sets of data, Biel, NABEL and the combination of Biel and NABEL. This serves in classifying the

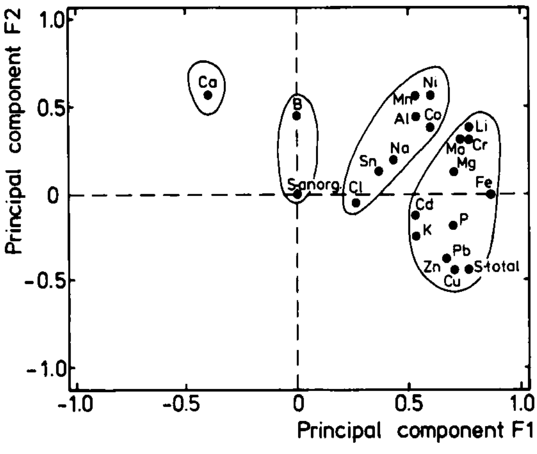

Figure 6 Principal component analysis: Presentation of the first two principal components (F1 * F2), collective Biel, all 21 elements.

elements according to their immission-ecological relevance. Figure 6 is a presentation of the results from the collective Biel.

In all 3 collectives, the 2 first principal components separate the elements into 3–4 groups, which account for 47–64% of the total variability according to the data collective.

Calcium always takes an isolated position. It is considered to be a macronutrient and is found in the highest quantities of all elements. It is the only element which shows a positive and highly significant correlation ($R = 0.87$***) to the total pollution indicator IAP18. Ca also shows significant correlations to several technical immission components.

Deposition measurements in the network of the Canton of Geneva[19] show no correlation though, between the Ca deposition (Jauges d'Owen, annual means) and the Ca contents of Hypogymnia physodes, estimated by means of IAP18. Keller *et al.*[16] found too, that in spruce needles only maximally 2% of the Ca content can be washed off with the needle wax. This can be interpreted to indicate that Ca derives primarily from the soil and not from the air.

Based on these results, calcium certainly cannot be counted to the air pollution group, even though a good correlation to the total pollution indicator IAP18 and to other technically measured pollutants exist. Once again, it is apparent how carefully correlation references must be interpreted, and how important additional differential diagnostic criteria are.

The unusual reaction of calcium indicates that in this case complex ion exchange processes are the cause of this difference in contents. In fact the analysis of the data shows that highly polluted sites, which show a low Ca value, prove to have even higher element contents of Fe, Pb, Zn and a number of other cations. It cannot be further defined here, in which manner such ion exchange processes take place, and whether it is a matter of purely passive or, as Puckett[20] notes, active processes in lichen.

A second group of elements are clustered around the element boron, namely anorganic sulfur (Sanorg), and in irregular order Na, Sn, K, Mg and Mn. This group includes typical macro-nutrients (K, Mg), while B and Mn belong to the micro-nutrients.

A third group, which in all three data collectives is not very clearly separated, unites typical micro-nutrients (Mn, Cl), the "useful" element Na and the non-participating substances Al, Co, Ni, Sn and Li, and according to the particular collective, also the macro-nutrients P, K and Mg. The latter is in Figure 6 just barely realized.

A comparison of these elements to the IAP18 (station means) reveals, that only Li and P in Biel and Al in the NABEL network show significant correlations, while the elements B, K, Mn, Na and anorg. sulfur do not correlate with the IAP18. Therefore, not much evidence exists that these elements are relevant to air pollution. They seem more to point out the chemical composition of the bark of the carrier tree, as well as of the soil characteristics of the study sites.

A very conspicuous fourth group of elements is comprised of the elements Pb, Cu, Zn, Fe, Cd, total sulfur (Stotal), Cr and Mo. According to the collective, this group is associated with further 2–3 elements. These element group contains those elements which, according to their priority, show good to very good correlations to the IAP18. And partly they can be set, by means of calibration, in a verified statistical relationship to the corresponding technically measured pollutants. The elements relevant in air pollution and immission ecology are herewith largely united. Keller *et al.*[16] show that for the elements Pb and Fe, according to the site characteristics, 78–82‰, resp. 44–82% of the total contents can be washed away with the needle wax, and therefore must be considered primarily of an airborne source.

OVERALL ASSESSMENT OF BOTH BIOINDICATION METHODS

The following conclusions can be drawn from the analysis of the Passive Biomonitoring Method:

—Several elements of biomonitoring with Hypogymnia physodes show significant and often very good correlations to the IAP18 air quality values. This method seems to be a genuine multi-indicator for air pollution, also for the content related point of view of the IAP18. It can truly be designated as a total air pollution indicator.

—The calibration of the monitoring method shows that the accumulation capacity of natural samples of Hypogymnia physodes, in the case of lead and copper, is just as good as for the artificially exposed samples of the Danish study (active biomonitoring).[12] Thereby, Passive Biomonitoring proves to be suitable for pointing out the trace element patterns of important air pollution elements. No transplants must be exposed in Passive Biomonitoring. Instead natural samples, which also do not need to be conditioned, a complicated process, are used. Therefore, the economical aspects are much more favourable than for active biomonitoring.

—The elements total sulfur, iron, calcium and lead also show good linkage to the technical pollution measurements in Biel and in the NABEL network. Multivariate comparisons show that these elements, to a certain degree, are also indicators of the total air pollution. It is an important fact though, that none of the elements prove to be as precise and stable for the indication of total air pollution as the indicator IAP18.

—The Passive Biomonitoring Method calls for a very strict sampling standardization. This is the only way that this method can produce precise and reproducible single pollutant measurements. This is verified by extensive methodical tests, which were conducted in a follow-up study.

—Even in the most highly polluted areas of the Swiss Midlands and bordering areas, the "Calibrated Lichen Indication Method" delivers more differentiated results. Otherwise in these areas biomonitoring techniques, which require lichen material for content analysis, are uncertain or even impossible because of insufficient sample material.

—The IAP18 possesses the advantage of being a nondestructive method which covers a whole biological community. That no plant material must be removed from the measuring site, is of great importance for success verifications after rehabilitation measures have been taken, resp. for the assessment of long-ranged pollution trends.

—The main field of application for biomonitoring with Hypogymnia physodes lies in the comprehensive characterization of single measuring sites and of whole regions. The possibility of providing a pollution cadastre for lead, copper, total sulfur, total nitrogen and other elements covering a selected area with much less expense than for a cadastre based on technical measurements, is of special interest. The method is also suitable for pollutant related and long-termed monitoring.

INTEGRATED BIOLOGICAL AIR POLLUTION—MONITORING SYSTEM FOR SWITZERLAND

A comprehensive standardized and calibrated testing system for measuring air pollution (Bioindikationsfächer)[21] has resulted from the combination of the Calibrated Lichen Indication Method and the Passive Biomonitoring Method presented here. In reference to the biological effects of air pollution (cadastre of biological effects) as well as the overview of the pollution situation (total immission cadastre) and single pollutant related measurements, this combined testing system is relevant for the Swiss Midlands and bordering regions.

The presented results fill important demands which are generally made on chemical and physical measuring methods.[21–23]

—The selectivity of the multi-element measurements (biomonitoring), as well as their reproducibility is, for the significant elements, good. The margin of error was defined in comparison measurements. Precision and reproducibility can be increased in the biomonitoring method by exact standardization in sampling.

—The Calibrated Lichen Indication Method is highly sensitive. Correlations to important parameters of technical air pollution measurements as well as to the accumulation contents (biomonitoring) of several elements, show that this method is also very well validated.

—Both methods are spatially and chronologically transferable, and are relevant in the Swiss Midlands and bordering areas.

—Both methods are representative, on one side, by the correlation of both systems with immission values, and on the other side, by the effect indicator (biological effects cadastre) of total air pollution. The significant correlation of the lichen indicator (German air purity index = Luftgüteindex, "Lugi") with the frequency of human respiratory tract illnesses[6] makes by analogy the "Integrated Biological Air Pollution Monitoring System" highly significant for man.

Both bioindication methods and the technical measuring methods complement each other. Together with the technically measured immission data, the presented methods represent a valuable technique for modern integrated immission control.

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